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BEVATRON OPERATION AND DEVELOPMENT. XXVIII

November 1960 through January 1961

Walter D. Hartsough and William W. Salsig

May 8, 1961

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ABSTRACT

The Bevatron operated an average of 80% of the scheduled operating time with the exception of one 5-day shutdown period for emergency maintenance of the motor generator sets. The machine was shut off 19% of the scheduled operating time because of component failure and 1% at the request of the user.

During and following the Christmas shutdown period an ultrasonic inspection was made of the flywheel keyway on each of the motor generator sets. No faults were apparent. Charpy samples were taken from the inspection bore in the flywheels. Subsequent "vee notch" Charpy impact tests indicated that the flywheels are operated in a brittle region rather than in the ductile range expected.

The research program again was devoted mainly to study of π- and K-meson interactions.

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OPERATION

Bevatron operation is summarized in Fig. 1 and Tables I and II.

RESEARCH

The physics research program carried out at the Bevatron during the calendar year 1960 is summarized in Table III. Table IV lists the research done during January 1961.

SHUTDOWNS

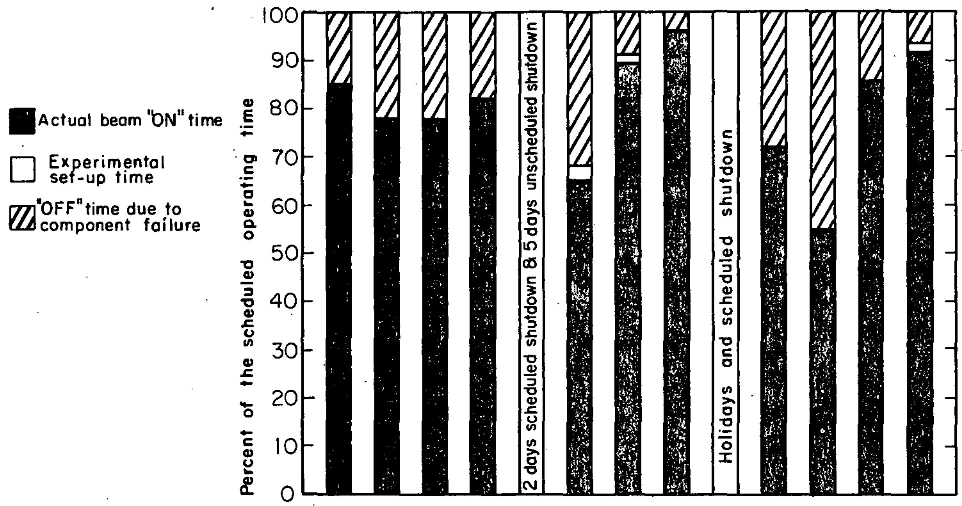
Following the Thanksgiving holiday, November 24 and 25, the Bevatron was shut off for repair and maintenance of the generator rotors. Inspection of the generators prior to start-up had revealed a faulty bolt-locking device on a rotor wedge of the west generator. (The bolt in question captures a strip that retains the insulation between the rotor poles and rotor wedges.) It was believed advisable to make a design change and install the new design on both generators. Operation was resumed on December 4. Two days of the above down period had previously been scheduled as a shutdown for change in experimental setup.

The Bevatron was shut down from December 23, 1960 through January 2, 1961 for the Christmas and New Year holiday period, and for ultrasonic inspection of the generator flywheels. The machine was shut down again from January 6 to 14 in order to complete the ultrasonic inspection and the evaluation of the flywheels (see below).

MAGNET POWER SUPPLY

Ultrasonic Inspection and the Evaluation of the Flywheels of the Motor Generator Set

The magnet power supply has been the largest source of outage in seven years of Bevatron operation, and has been under critical review, from the standpoint of correcting trouble before it occurs, for the past two years. By examination of the stress posture of the flywheels, the keyway was shown to be a severe notch. Indeed, at every start-up of the machines, the metal at the corner of the keyway stretches plastically, and is compressed again when the units are turned off. Compounding this problem are numerous large voids and inclusions in the flywheel steel—typical of 12-in.—thick plate—that make it unreasonable to attempt to forecast an expected life for the keyway-corner condition.



Week of	10/30	11/6	11/13	11/20	11/27	12/4	12/11	12/18	12/25	1/1	1/8	1/15	1/22
Crew hours	168	168	168	120	168	168	168	120	72	120	168	168	168
Turn on and maintenance time (hr)	9	9	9	8	120	9	9	5	0	10	10	9	9
Scheduled operating time (hr)	159	159	159	112		159	159	115	0	70	14	159	159
Scheduled Bevatron test time (hr)	0	0	0	0	0	0	0	0	0	0	0	0	0
Scheduled shutdown time (hr)	0	0	0	0	48	0	0	0	72	40	144	0	0
Holiday (hr)	0	0	0	48	0	0	0	48	96	48	0	0	0

MU-23649

Fig. 1. Bevatron operating schedule November 1960 through January 1961.

Table I. Beam record

Week of (1960-1961)	Number of 8-hour shifts	Total integrated beam (10^{15} protons)
Oct. 30 - Nov. 5	21	8.7
Nov. 6 - 12	20	8.3
Nov. 13 - 19	21	9.2
Nov. 20 - 26	12	6.1
Nov. 27 - Dec. 3	shutdown	
Dec. 4 - 10	20	6.5
Dec. 11 - 17	21	11.0
Dec. 18 - 24	15	10.6
Dec. 25 - 31	shutdown	
Jan. 1 - 7	10	5.1
Jan.8 - 14	1	0.8
Jan. 15 - 21	21	13.0
Jan. 22 - 28	21	13.9[a]

Maximum beam amplitude at full energy = 3.1×10^{11} protons per pulse
Maximum injected beam = 575 μa
Average beam per 8-hour shift = 5.1×10^{14} protons

[a]Beam level was reduced at the request of the user.

Table II. Analysis of the total lost beam time due to component failure (%)

Month (1960-1961)	Injector	Magnet power supply	rf Accelerating system	Other
November	12	81	2	5
December	25	45	8	22
January	33	33	21	13

Table III. Summary of bevatron experimental research program, January - December 1960

Group	Start of experiment	End of experiment	Experiment	Beam time (12-hour periods)	Beam time (hours)	Pulse schedule	Primary or secondary experiment
Internal Groups							
Lofgren	10-29-59	1-31-60	K^+-meson interactions in hydrogen and deuterium (220 to 875 Mev/c).	36	403	1:2	P
Barkas	1-19-60	1-23-60	Emulsion exposure (2-Bev/c μ^-).	—	—	1:2	S
Barkas	1-22-60	1-22-60	Emulsion exposure (3.5-Bev/c π^-).	—	—	1:2	P
Powell	1-26-60	1-31-60	π^+-p scattering (730 Mev/c).	7	69	1:2	P
Powell	2-13-60	5-20-60	K-meson interactions and θ_1-θ_2 mass difference (700-Mev/c K^+).	73	500 319	1:1 1:2	P
Lofgren	2-13-60	3-15-60	K^--p and K^--n scattering (1.5 Bev/c).	39	443	1:1	P
Segrè	3-18-60	4-19-60	π-π scattering (1.5 Bev/c).	43	469	1:1	P
Alvarez	4-22-60	in progress	$\pi^\pm$ interactions in hydrogen and deuterium using the 72-in. hydrogen bubble chamber (0.9 to 1.6 Bev/c).	213 38	2124 436	1:1 1:2	P
Lofgren	5-12-60	8-25-61	Test of an argon spark chamber in a π-meson beam; π^--p recoil polarization (700 to 1000 Mev/c).		138 22	1:1 1:2	S
Glaser	5-23-60	6-7-60	Measure θ_1^0 branching ratio using Xe bubble chamber (700-Mev/c K^+).	25	117 139	1:1 1:2	P
Moyer	6-9-60	7-20-60	π^--p elastic scattering and differential cross sections (550 to 925 Mev/c).	75	746	1:1	P
Alvarez	8-9-60	in progress	Study K^- interactions in hydrogen using the 15-in. hydrogen bubble chamber (740 Mev/c).	108 34	1145 330	1:1 1:2	P
Thornton	9-8-60	11-22-60	K^- total cross sections (500 Mev/c to 1 Bev/c).	43	482	1:1	P
Barkas	11-1-60	11-4-60	Emulsion exposure (700-Mev/c K^-).	5	58	1:1	S
Lofgren	12-7-60	in progress	Study of K^+-p and K^+-n total cross sections and elastic scattering (1 to 3 Bev/c).	14	162	1:1	P
Seaborg	Chemistry target bombardments (35) in the internal proton beam.						

Table III. (continued)

Group	Start of experiment	End of experiment	Experiment	Beam time (12-hour periods)	Beam time (hours)	Pulse schedule	Primary or secondary experiment
External Groups							
Institution and Experimenter							
Princeton U. Fitch	12-2-59	1-6-60	Study θ_1-θ_2 mass difference	8	69	1:1	P
U. Washington Masek	1-8-60	2-3-60	μ-meson scattering in lead and carbon (3.5-Bev/c π^-).	46	515	1:1 1:2	P
Tufts Univ. Schneps	1-22-60	1-22-60	Emulsion exposure (3.5-Bev/c π^-).	—	—	1:2	P
U. Tennessee King	1-22-60	1-22-60	Emulsion exposure (3.5-Bev/c π^-).	—	—	1:2	P
U. Wisconsin Fry	1-22-60	1-22-60	Emulsion exposure (3.5-Bev/c π^-).	—	—	1:2	P
Tata Inst., India Biswas	1-22-60	1-22-60	Emulsion exposure (3.5-Bev/c π^-).	—	—	1:2	P
U. Washington	1-22-60	1-22-60	Emulsion exposure (4.5-Bev/c π^-).	—	—	1:2	P
U. Michigan Jones, Perl	4-1-60	8-10-60	π^--p elastic differential scattering cross section (1.5, 2.0, 2.5 Bev/c).	6	64	1:2	S
U. Michigan Jones, Perl	8-10-60	9-4-60		38 30	437 318	1:1 1:2	P
U. Washington	6-2-60	6-22-60	Study π^- in emulsions in high magnetic field (0.7 to 1.5 Bev/c).	10	119	1:1	S
U. Michigan Vander Velde	6-29-60	8-26-60	Study energy loss of π mesons in a silicon solid-state ionization chamber.	5	67	1:1	S
Princeton U. Cronin	7-6-60	7-20-60	Spark-chamber tests in a π-meson beam.	No record kept			S
Univ. Ohio Randall	8-19-60	8-19-60	Emulsion exposure (2.5-Bev/c π^-).	—	1	1:1	P
Northwestern U. Ammar	9-6-60	9-13-60	Emulsion exposure (740-Mev/c K^-).	5 9	60 56	1:1 1:2	S
Duke Univ. Block	9-12-60	10-3-60	Test of a helium bubble chamber in a 1-Bev/c π^- beam.	15 2	169 19	1:1 1:2	S
Univ. Chicago	9-20-60	9-23-60	Emulsion exposure (740-Mev/c K^-).	5	54	1:1	S
U. Washington Kim	9-21-60	9-21-60	Emulsion exposure (2-Bev/c π^-) (background measurement).	—	1	1:1	S
U. Wisconsin Fry, Good			This experiment is the same as the Alvarez 72-in. bubble-chamber experiment. Running time is included in the Alvarez-group totals.				P
U. Maryland and N.R.L. Steinberg	12-9-60	12-9-60	Emulsion exposure (790-Mev/c K^-).	1	10	1:1	S
U. Amsterdam Holland Tenner	12-16-60	12-16-60	Emulsion exposure (790-Mev/c K^-).	1	11	1:1	P
London Univ. England Burhop	12-16-60	12-16-60	Emulsion exposure (790-Mev/c K^-).	1	10	1:1	P
Weizmann Inst. Israel Eizenberg	12-16-60	12-16-60	Emulsion exposure (790-Mev/c K^-).	1	7	1:1	P

Table IV. Summary of bevatron experimental research program, January 1961

Group	Start of experiment	End of experiment	Experiment	Beam time (to date) (120-hour periods)	Beam time (to date) (hours)	Pulse schedule	Primary or secondary experiment
Internal Groups							
Alvarez	4-22-60	in progress	$\pi^{\pm}$ interactions in hydrogen and deuterium using the 72-in. hydrogen bubble chamber (0.9-1.6 Bev/c).	217 38	2163 436	1:1 1:2	P
Alvarez	8-9-60	1-24-61	K^{-} interactions in hydrogen and deuterium using the 15-in. hydrogen bubble chamber (740 Mev/c).	119 34	1279 330	1:1 1:2	P
Lofgren	12-7-60	1-31-61	K^{+}-p and K^{+}-n total cross sections and elastic scattering (1 to 3 Bev/c).	22 10	248 106	1:1 1:1	P S
Lofgren	1-27-61	1-31-61	π^{+}-p scattering, measurement of angular distribution (1.5, 2.0, 2.5 Bev/c).	3	25	1:1	S
Seaborg	Chemistry target bombardments (3) in the internal proton beam.						

Table IV (continued)

Group	Start of experiment	End of experiment	Experiment	Beam time (to date) (12-hour periods)	Beam time (to date) (hours)	Pulse schedule	Primary or secondary experiment
<u>External Groups</u>							
Institution and Experimenter							
Univ. Chicago Northwestern U. Levi Setti	1-14-61	1-23-61	Emulsion exposure (800-Mev/c K^-). Study of production of hyperfragments.	9	106	1:1	P
Duke University Block	1-27-61	in progress	Study of K^- interactions in a helium bubble chamber (740 Mev/c).	3	25	1:1	P

After considerable discussion with technical factory personnel, the decision was reached to bore ultrasonic inspection holes a few inches above the keyways, so that one might then detect development of a crack before a disaster occurred (a remote but finite possibility), and shut down. Such discussions raised serious concern that a 9-month gap in operation could result while awaiting new parts; therefore, it was decided to correct the hazard.

It was found that the most economical correction would be to acquire new flywheel shafts, of larger hub diameter, and mount the existing flywheels on these new shafts, with appropriate keyway corrections. Professor Earl Parker (University of California, Berkeley), an expert on brittle failure, concurred in this procedure, provided one could prove that the existing flywheels had adequate ductile-to-brittle behavior characteristics. He suggested that the flywheel steel must show 20 ft-lb minimum rupture energy (vee notch Charpy impact test) at 32° F before the flywheels were considered for reuse.

Accordingly, core samples were taken when the ultrasonic inspection holes were put in during the 1960 Christmas Holiday shutdown. The Charpy test results were very disturbing. The flywheels were found to be operating in the fully brittle region (6 ft-lb Charpy), and no achievable increase in operating temperature would bring them into the ductile range. We thus had fulfilled 2-1/2+ of the three conditions necessary and sufficient for a sudden brittle rupture: (a) steel operating in the fully brittle range, (b) sufficient energy stored in the system to propagate a crack if once formed, and (c) a notch condition adequate to initiate a crack. (Unfortunately, brittle-failure criteria were not sufficiently understood at the time the parts were originally fabricated to ensure a completely safe design.) In addition, the first ultrasonic inspection indicated discontinuities in the most critical part of the keyway notch, possibly at two places.

The generators were shut down once more and factory personnel were called into consultation again. Mr. R. E. Peterson, Manager of Mechanics Division, Westinghouse Research Laboratories, brought with him convincing experimental data which indicated that there must be a specific crack length for the type of steel used in the flywheels before rupture would proceed catastrophically. It appeared that thorough ultrasonic monitoring would detect this magnitude of defect in time to prevent an accident. Detailed examination, including removal of part of a key, proved that no existing faults of consequence were yet apparent in the critical notches. The generators were returned to operation, subject to weekly ultrasonic monitoring—which would be continued until replacement parts were available. Negotiations on the specification for new flywheels took 8 weeks, then orders were placed for new equipment with adequate brittle-failure protection. Our engineering personnel believe this to be the first instance in which steel manufacturers have ever guaranteed a specific Fracture Appearance Transition Temperature—a step made possible by the recent development of vacuum-pouring techniques for steel.

Magnet Pulse Record

The magnet pulse record appears in Table V.

ACKNOWLEDGMENTS

The Bevatron operating crew supervisors are Duward Cagle, Frank Correll, Ross Nemetz, and Glenn White. Crew members are Robert Allison, G. Stanley Boyle, Ashton Brown, Gary Burg, Norris Cash, Ferdinand Dagenais, Raleigh Ellisen, Robert Gisser, William Kendall, William Lee, Wayne Logan, Kenneth Morgan, and Joseph Smith. Edward J. Lofgren is the Bevatron Group Leader; William A. Wenzel is the alternate group leader. Walter D. Hartsough, with Glen R. Lambertson and Wendell Olson assisting, is in charge of Bevatron operation. Support and development projects were carried out by Robert Anderson, Trancuilo Canton, Warren Chupp, Bruce Cork, Kenneth Crebbin, Rudin Johnson, Leroy Kerth, Glen Lambertson, Fred Lothrop, Robert Richter, William Wenzel, Emergy Zajec, and Theodore Zipf. Engineering groups were headed by Edward Hartwig, Electrical Engineering; Clarence Harris, Electrical Coordination; and William Salsig, Mechnical Engineering. Donald Milberger was in charge of the Electrical Maintenance Group.

This work was done under the auspices of the U. S. Atomic Energy Commission.

Table V. Bevatron motor-generator set monthly fault report

	4 to 6 pulses per minute						7 to 9 pulses per minute						10 to 17 pulses per minute						Totals				
	1500 to 6900 amp			7000 to 9000 amp			1500 to 6900 amp			7000 to 9000 amp			1500 to 6900 amp			7000 to 9000 amp			Number of pulses	Number of faults		P/F	Ignitrons replaced
MONTH	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F	Pulses	Faults	P/F		Arc-backs	Arc-throughs		
1960																							
January	4809		--	2289	2	1145	510	1	510	701		--	5254	2	2627	368039	68	5412	381602	23	50	5227	--
February	927	1	927	1097		--	--		--	--		--	5519		--	248528	44	5648	256071	5	40	5690	--
March	144		--	1062		--	770		--	735		--	7501		--	387451	87	4453	397612	16	71	4909	4B2
April	400		--	--		--	--		--	--		--	4449		--	324768	40	8119	329617	10	30	8240	--
May	--		--	--		--	--		--	--		--	4683	3	1561	419546	43	9759	424229	12	34	9222	--
June	--		--	--		--	--		--	1168		--	3337		--	410794	63	6520	415299	5	58	6592	--
July	--		--	--		--	1887		--	--		--	1857		--	259094	61	4248	262838	14	47	4309	1B4, 2B4, 2B6, 3B1
Aug.	--		--	--		--	4139		--	--		--	9371		--	311852	69	4519	325362	12	58	4648	--
Sept.	--		--	--		--	--		--	--		--	5157		--	365832	52	7035	370989	13	39	7134	--
Oct.	--		--	--		--	--		--	--		--	24830		--	375822	47	7997	400652	14	33	8525	--
Nov.	--		--				614			1523			5862			292096	74	3948	300127	15	61	3950	2A4
Dec.	2374									3244			2580			223964	29	7723	232162	1	28	8006	
Jan.	2201			1200			5099								6671	277091	59	4697	292062	24	35	4951	

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